SHALLOW GROUND WATER AND RELATED HAZARDS IN UTAH

By Suzanne Hecker, Kimm M. Harty, and Gary E. Christenson

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ABSTRACT

A STATEWIDE compilation of shallow ground-water information indicates that water less than 30 feet (9.1 m) deep in unconsolidated deposits underlies about 15 percent of Utah. Most shallow ground water occurs in central basin areas and stream valleys in the western half of the state and is maintained by surface-water infiltration and upward leakage from underlying artesian systems. Ground water is less than 10 feet (3.1 m) deep throughout the extensive salt flats of the Great Salt Lake Desert, around Great Salt Lake, and beneath wet playas, along streams, and near lakes in many lowland areas of the Basin and Range. With the exception of the Uinta Basin, shallow ground water in the eastern Colorado Plateau is generally localized in the bottoms of narrow canyons. In the western Colorado Plateau and Middle Rocky Mountains, shallow ground water occurs chiefly in valley-bottom areas between plateaus and ranges.

Many population centers in the state are in areas susceptible to shallow ground-water problems. Rising water tables in recent years have caused flooding in basements, storage tanks, underground utilities, waste dumps, and septic-tank soil-absorption fields. Such rises in water tables have mobilized contaminants and threatened local ground-water quality. Areas with the potential for large earthquakes, such as the Wasatch Front, are vulnerable to damage caused by liquefaction of cohesionless silty and sandy deposits saturated at shallow depths. Site-specific data on the distribution of shallow ground water in Utah are lacking. This statewide compilation of available regional information provides a basis for deciding where detailed planning-related studies may be needed in order to identify and mitigate shallow ground-water hazards and avoid costly corrective measures.

INTRODUCTION

Water in saturated zones beneath the land surface, referred to as ground water, occurs in various materials and at various depths throughout Utah. Ground water fills fractures and pore spaces in rocks and fills voids between grains in unconsolidated deposits (clay, silt, sand, and gravel). Unconsolidated deposits that are saturated at shallow depths, generally less than 30 feet, present problems for land development and thus are a concern to the many urbanized areas of Utah underlain by these deposits. This report and the accompanying map describe and delineate the general occurrence of shallow ground water in unconsolidated deposits for the purpose of providing state and local government planners, and geotechnical consultants, developers, and others in the private sector with a guide to areas where ground-water-related hazards to land development may be expected.

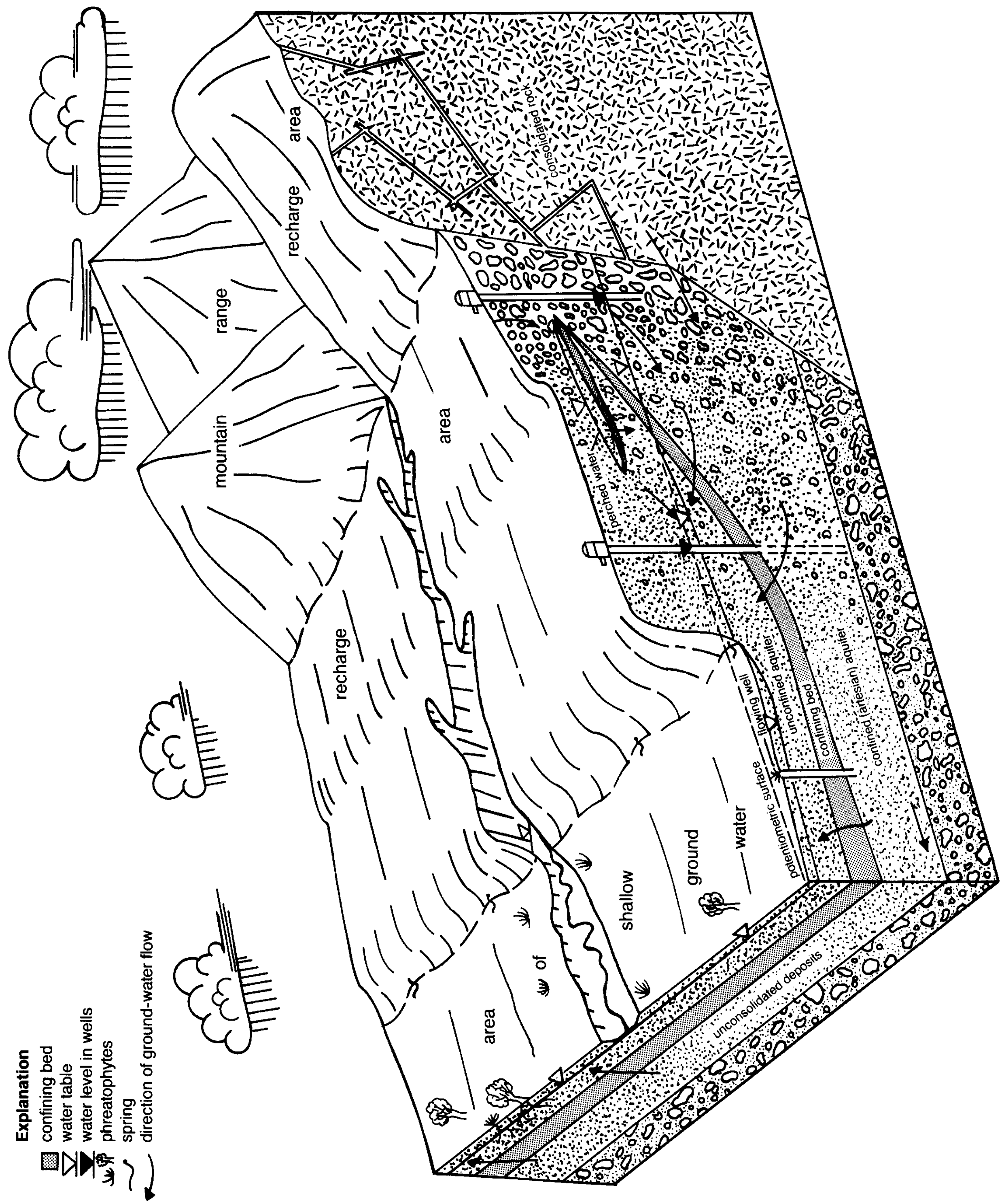

Figure 1. Relation of unconfined, confined, and perched ground water in typical basin or wide stream valley. In the well at right, the water level corresponds to the water table; in the other two wells, which tap the confined aquifer, the water rises above the confining layer and the water table to the potentiometric surface. (Modified from Hely and others, 1971.)

Ground water in unconsolidated deposits, chiefly stream alluvium and alluvial-fan and lacustrine (lake) basin fill, occurs under unconfined and confined conditions and frequently occurs in geologic units, known as aquifers, which are permeable enough to yield water in usable quantities to wells or springs (Heath, 1983). An unconfined aquifer is not saturated for its entire thickness, and the water table marks the top of the saturated zone (figure 1). Localized occurrences of unconfined ground water above the principal water table are called perched zones (figure 1). Where ground water saturates the entire thickness of an aquifer below a low-permeability zone, termed a confining bed, the aquifer is said to be under confined conditions. Ground water beneath or within a confining bed is usually under artesian pressure, and water in wells penetrating a confined aquifer usually rises above the top of the aquifer to the level of the potentiometric surface (figure 1). In unconfined ground water, the potentiometric surface is simply the water table. Flowing wells are produced where the potentiometric surface of a confined aquifer rises above the ground surface. Confining beds in unconsolidated deposits are generally semi-permeable and thus allow underlying, artesian water to leak through and help maintain a water table above the confined aquifer (figure 1).

Water in shallow saturated zones is replenished by infiltration from streams, lakes, and precipitation, lateral subsurface flow from adjacent higher ground-water areas, and upward leakage of underlying confined water. The shallowest water tables are generally found in stream valleys and in the center of basins where upward leakage from underlying artesian systems is greatest and potentiometric surfaces are highest (figure 1). Ground water discharges naturally from springs and by evapotranspiration (direct evaporation and plant transpiration). Man influences local water levels through irrigation, pumping, and surface-drainage diversions and reservoirs.

Shallow ground water in unconsolidated deposits presents several problems for land development. It causes unstable excavations and foundations, flooding of subsurface facilities, and occasional surface flooding. In addition, shallow ground water is a prerequisite for an earthquake hazard known as liquefaction. Ground shaking during earthquakes can cause loss of strength in low-density silts and sands that are saturated at shallow depths (generally less than 30 feet). This loss of bearing strength can cause settlement, ground cracking, or slope failure, resulting in damage to structures (National Research Council, 1985).

Shallow ground water in rock, a much less common phenomenon in Utah, has not been considered for the map because it poses a relatively insignificant geotechnical hazard. Foundations and conventional waste-water disposal systems in rock are uncommon, and foundation stability is not appreciably reduced by saturated conditions. Also, rock is not susceptible to liquefaction.

The shallow water table is dynamic and fluctuates daily, seasonally, annually, and over longer periods in response to a variety of conditions. Ground-water levels may rise and fall with seasonal variations in precipitation, longer-term changes in climate, or changes in rates of irrigation and pumping. Annual reports on ground-water conditions in Utah, prepared by the U.S. Geological Survey and Utah Division of Water Resources, document water-level changes (in confined as well as unconfined aquifers) in many areas of the state. A series of years with greater-than-average precipitation beginning in the late 1960s, but particularly since 1982, has increased ground-water recharge to basins and has generally elevated ground-water tables statewide. Depths to water on a map of shallow ground water are necessarily shown to be static. In actuality, however, water depths at a given location change with time.

METHODOLOGY AND SCOPE

Two approximate depth-to-water contours are shown on the shallow ground-water map. Areas with water tables less than about 10 feet below the land surface are delineated to depict zones most likely to experience ground-water-related problems. Areas where the depth to water is generally less than about 30 feet are also shown because of the potential for liquefaction in some deposits at these depths. The 30-foot contour may include areas of water less than 10 feet deep that either are too small or lack data to be mapped separately, or that occur due to short-term water-table fluctuations. Page 18 is an index map of data sources used to compile the contours.

Little work on ground water specifically addresses shallow ground-water conditions. Where available, data from shallow wells completed in unconsolidated deposits and depth-to-water maps derived from such data were the basis for mapping shallow ground water. However, water levels in most wells pertain to deep, confined aquifers which provide municipal, domestic, or irrigation water and thus may reflect potentiometric surfaces related to artesian pressure and not the water table. Flowing wells indicate zones where the potentiometric surface of confined aquifers is above the land surface. Upward leakage through confining layers is common in such areas of high artesian pressure, and thus zones of flowing wells were used to indicate areas of probable shallow ground water. In many other shallow ground-water areas, artesian potentiometric-surface depths are apparently about equal to water-table depths, and thus maps of potentiometric surfaces could often be used to estimate shallow ground-water contours.

Maps of phreatophyte (ground-water-fed plant) growth were also used to indicate depths to ground water. Phreatophyte assemblages are commonly correlated with water-depth intervals based on root-penetration depths. Although phreatophytes are a more indirect indicator of shallow ground-water conditions than water levels, their areal extent does not vary with short-term fluctuations in ground-water depths. Long-term water-level changes, however, may have caused shifts in phreatophyte distributions since the earliest maps were produced.

Topographic and geologic information provided a check on the distribution of shallow ground water and provided primary control where well and other data were sparse. In places, topography was used to extrapolate between data points in order to define low-elevation, low-relief areas of probable shallow ground water. Marshes and springs in such areas shown on topographic maps provided clear evidence of shallow ground water. The extent of playa or flood-plain deposits augmented well and/or topographic control in low areas, and contacts between rock and unconsolidated deposits locally served to define shallow ground-water contours for the unconsolidated deposits.

The map represents a generalized composite of well and phreatophyte data collected in different years and seasons over several decades with varying precipitation. Whereas precipitation in the late 1940s through the mid-1960s was less than average, precipitation in the last two decades has been generally greater than average, and the early 1980s were particularly wet. Consequently, the mapped shallow ground-water areas indicate a likelihood of water occurring at shallow depths but do not depict modern, contemporaneous conditions throughout the state. The historic high stand of Great Salt Lake near 4212 feet (1283.8 m), reached in 1873 (Currey and others, 1984) and again in 1986, encompasses areas that were underlain by shallow ground water when the lake was the size shown on the base map. Rising lake levels in recent years have probably been accompanied by increases in ground-water levels immediately adjacent to inundated areas, but the extent of affected areas has not been well documented. Other, smaller lakes and playas in Utah have also experienced recent surface flooding, but such flooding is not indicated on the map.

It has been necessary to generalize shallow ground-water areas because of the small scale of the map. The map does not show most zones of shallow perched water or shallow ground water near most streams or springs. Conversely, local areas of deeper water, such as beneath isolated topographic highs, may be incorporated within areas of mapped shallow ground water. Data resolution varies between mapped areas, and some shallow ground-water areas may not appear on the map due to lack of data.

OCCURRENCE OF SHALLOW GROUND WATER

To facilitate the discussion of shallow ground water, the state has been divided as shown in figure 2. Three major regions have been defined based on physiography: 1) the Basin and Range, 2) the Colorado Plateau, and 3) the Middle Rocky Mountains. These regions have been subdivided into areas convenient for the discussion of shallow ground-water occurrence. Following a brief overview of shallow ground water in each major region, details are provided on the occurrence of shallow ground water and the data used to delineate shallow ground-water contours in each area.

BASIN AND RANGE

The Basin and Range physiographic province consists of wide, flat, north-trending, structural basins separated by narrow, linear mountain ranges. Many of the basins are topographically closed, and virtually the entire region is internally drained. Thick accumulations of lacustrine and alluvial basin fill contain abundant ground water and generally shallow water in central areas of the basins. Most of Utah's shallow ground water occurs in this region.

Valleys North of the Great Salt Lake Desert

Shallow ground water in Grouse Creek Valley occurs chiefly in young stream alluvium in flood plains and along adjacent valley slopes. Depths to ground water in different parts of the valley vary from 0 to greater than 50 feet (15.2 m). The 30-foot ground-water contour for this area was drawn from depth-to-water categories mapped by Hood and Price (1970) using phreatophyte distribution. Included within this contour are categories of ground-water depths ranging from 0 to 30 feet, 20 to 50 feet (6.1-15.2 m), and 20 to more than 50 feet. Well data were insufficient to interpolate a 10-foot ground-water contour or to refine the 30-foot contour.

Shallow ground water surrounding, and west of, the towns of Park Valley and Rosette occurs in unconsolidated alluvial and lacustrine deposits. Ground-water contours were drawn using depth-to-water categories which are based largely on phreatophyte distribution (Hood, 1971). The 30-foot ground-water contour conforms to Hood's 0- to 30-foot depth-to-water category and also includes a 0- to 10-foot category corresponding to areas too small to differentiate on the map. A map showing static water levels in wells tapping alluvium (Montgomery and Everitt, 1984) generally supports the 30-foot ground-water contour taken from the phreatophyte map.

North-Shore Valleys of Great Salt Lake

Shallow ground water occurs in areas along the north shore of Great Salt Lake, in the salt flats west of the Promontory Mountains, and in the lower parts of Hansel and Curlew Valleys. These areas contain fine-grained lacustrine sediments that are commonly saturated and occur in marsh lands within the 10-foot contour near the lake. Ground-water contours were drawn using depth-to-water maps based on phreatophyte distribution (Bolke and Price, 1969; Hood, 1971, 1972; Stephens, 1974a). In areas near Great Salt Lake, the position of the 10-foot ground-water contour may vary with fluctuations in the level of the lake. Currently, much land within the 10-foot contour adjacent to the lake is inundated due to the recent rising of the lake level.

Lower Bear River Drainage Area

Saturated conditions characterize the wide, flat valley of the lower Bear and Malad Rivers. Layers of fine- and coarse-grained lacustrine and alluvial deposits create complex ground-water divisions within the valley reservoir. Leaky confined conditions with potentiometric surfaces near or above the land surface occur in all but the margins of the valley and contribute to shallow ground water throughout much of the area. North of Tremonton, a separate, shallow unconfined system extends beyond areas of near-surface artesian pressure. Small, discontinuous, perched zones occur chiefly in deposits marginal to the valley, and shallow perched water (not mapped) is present at the south end of West Hills and in a valley between West Hills and Blue Springs Hills. Shallow

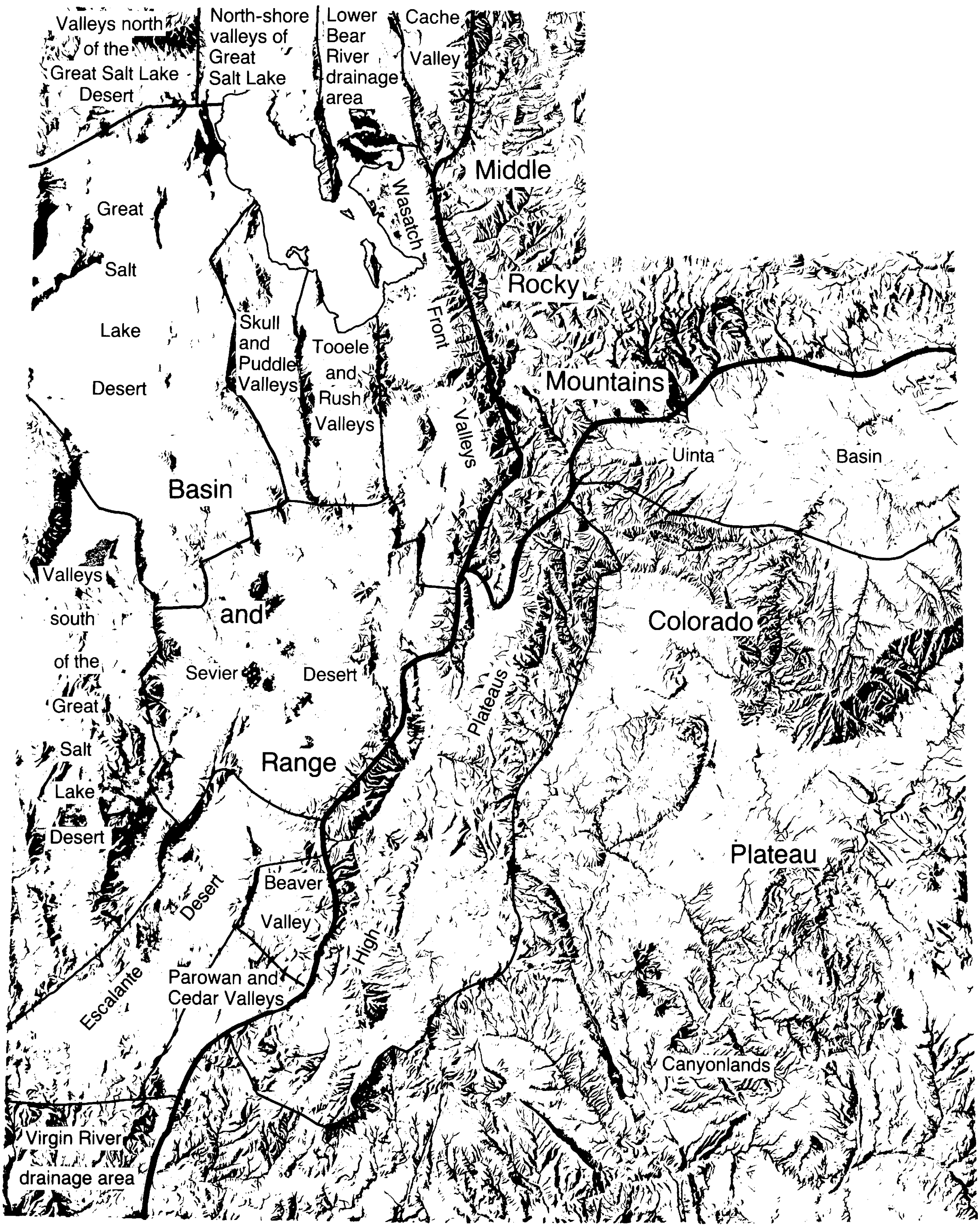

Figure 2. Major physiographic regions(▬▬) (Hunt,1967) and areas (——) used to discuss shallow ground-water occurrence.

water discharges from the lower Bear River area through evapotranspiration and flows into drains and streams (Bjorklund and McGreevy, 1974).

The extent of shallow ground water was delineated from a map showing depths to potentiometric surfaces (Bjorklund and McGreevy, 1974). Large areas of flowing wells generally coincide with open-water areas, springs, mud flats, wetlands, and phreatophyte growth, indicating shallow water depths. Water-level depths increase too sharply beyond the area of flowing wells to delineate both 10- and 30-foot contours. However, because ground-water depths in most of the area are less than 10 feet, the 20-foot contour of Bjorklund and McGreevy (1974) was used to approximate the 10-foot contour. The mapped extent of the shallow unconfined system (Bjorklund and McGreevy, 1974) was used to approximate the distribution of water less than 10 feet deep north of Tremonton. Mapped natural discharge areas (Bjorklund and McGreevy, 1974) were used to extend water-level mapping adjacent to the Bear River.

A relatively small area of shallow ground water was mapped west of the lower Bear River in Blue Creek Valley near Howell. This area supports scattered phreatophytes and is a discharge zone where ground-water depths are less than about 20 feet (Bolke and Price, 1972).

Cache Valley

Wetlands and shallow ground water are common in the broad lowlands of Cache Valley. Shallow ground-water levels are maintained principally by upward seepage through confining layers and infiltration of irrigation water. Leaky confined ground-water conditions with potentiometric surfaces at or above the land surface commonly extend to near valley margins and roughly coincide with the extent of shallow ground water. Shallow perched water has been found in excavations, and a perched water table has been defined at the south end of the valley near Hyrum (Bjorklund and McGreevy, 1971).

The distribution of shallow ground water in Cache Valley was delineated using a depth-to-potentiometric-surface map (Bjorklund and McGreevy, 1971). Areas of marshes, phreatophyte growth, and springs generally occur in the area where potentiometric surfaces are above-ground, indicating that the surface depths could be used to estimate depths to shallow ground water. Well data indicate that the 30-foot contour bordering Cache Valley could be approximated using the 50-foot potentiometric-surface-depth contour, except at the south end of the valley near Paradise where well and topographic constraints were used. The 10-foot contour was taken from the corresponding water-level-depth contour and was extended in the vicinity of Hyrum to incorporate local perched ground water.

Wasatch Front Valleys

Shallow ground water occurs extensively in alluvial and lacustrine deposits in Juab, Utah, Cedar, Goshen, and Salt Lake Valleys, and along the east shore of Great Salt Lake in Davis, Weber, and Box Elder Counties. A shallow water table exists over much of the region, and zones of perched ground water (not mapped) occur locally along stream channels and under benchlands (Bolke and Waddell, 1972; Clark and Appel, 1985). Shallow ground-water conditions in the Wasatch Front result partly from recharge by runoff from the Wasatch Range and other mountains bounding the valleys and partly from upward leakage from extensive artesian aquifers. Irrigation of crops and lawns in this urbanized region also contributes to the shallow water tables.

Ground-water contours in Utah, Salt Lake, and Davis Counties reflect relatively detailed information taken from depth-to-water maps compiled from borehole data for liquefaction potential mapping (Anderson and others, 1982, 1986a, 1986b). In the Cedar Valley area of Utah County, contours were modified using soil survey data (Trickler and Hall, 1984). Ground-water contours for northern Juab Valley were taken from a depth-to-water map on which the water table and other potentiometric surfaces are considered to be coincident (Bjorklund, 1967). Ground-water contours in Weber and southeastern Box Elder Counties are based largely on potentiometric surfaces (Bedinger and others, 1984b), which in this area too are considered to accurately represent zones of shallow ground water.

Tooele and Rush Valleys

Shallow ground water occurs in the lacustrine deposits at the north end of Tooele Valley, where upward leakage from artesian aquifers adds water to the shallow water-table zone (Razem and Steiger, 1981). Here, depths to water are generally less than 10 feet, as indicated by test holes and phreatophyte mapping (Razem and Steiger, 1981). A 30-foot ground-water contour is not shown on the map, because it is essentially coincident with the 10-foot contour. Notable water-level increases have occurred recently in the northern part of Tooele Valley, particularly in the Erda area, probably due to increased recharge caused by above-average precipitation (Razem and Steiger, 1981). Recent rises in Great Salt Lake, in addition to inundating portions of northern Tooele Valley, may be causing a small up-valley increase in the extent of shallow ground water.

Shallow ground water occurs in many places in Rush Valley, notably in alluvium in the southwest near Vernon and in lacustrine sediments in the northwest near Rush Lake. Water levels have risen during the early 1980s in the Clover and St. John areas due to above-average recharge (Razem and Steiger, 1981). Ground-water contours were taken from maps that depict phreatophyte distribution and incorporate depths to water in wells (Hood and others, 1969). The 10-foot ground-water contours encompass phreatophyte zones where water depths range from 0 to about 20 feet. The 30-foot contour includes phreatophyte areas corresponding to water depths of 20 to 50 feet, as well as bare ground where water is 15 to 25 feet (4.8-7.6 m) below the ground surface.

Skull and Puddle Valleys

Shallow ground water occurs in lacustrine sediments at the south end and in the north half of Skull Valley and along the shore of Great Salt Lake west of Puddle Valley and the Lake-side Mountains. In these areas, water moves to shallow water tables by upward leakage through confining layers and is discharged through evapotranspiration and spring flow. Shallow ground water was mapped using the association of general water depths with mapped occurrences of moist to wet bare ground and phreatophyte assemblages (Hood and Waddell, 1968; Price and Bolke, 1970). Marsh lands and mud flats adjacent to Great Salt Lake, including salt flats where ground water discharges by direct evaporation, apparently coincide with areas where water is less than 5 feet (1.5 m) deep and thus were used to draw the 10-foot contour. Generally drier land phreatophytes, mapped as a single unit, have water-depth associations of 0 to 40 feet (0-12.2 m) and were used to draw the 30-foot contour. Isolated 30-foot contours within areas where water is less than 10 feet deep result from landforms, such as sand dunes, that are slightly higher than the surrounding valley floor.

In contrast to Skull Valley, Puddle Valley has no significant areas that discharge ground water through evapotranspiration because water generally lies at depths of 100 to 300 feet (30.5-91.4 m). Local shallow conditions occur only where water is perched and where the valley joins the Great Salt Lake Desert to the north (Price and Bolke, 1970).

Great Salt Lake Desert

Ground water is shallow throughout the fine-grained lacustrine deposits of the Great Salt Lake Desert. Brine saturates the crystalline salts of the Bonneville Salt Flats and the surrounding saline mud flats. Because the Great Salt Lake Desert is a large basin of interior drainage, flow into brine-collection ditches in the Salt Flats and evapotranspiration are the principal forms of discharge from the ground-water system (Stephens, 1974a; Gates and Kruer, 1981). Water pumped from Great Salt Lake to the Great Salt Lake Desert, beginning in the spring of 1987, has created a large, shallow lake in the northeast part of the basin.

The distribution of shallow brine, mapped on the basis of a series of shallow auger holes (Stephens, 1974a; Gates and Kruer, 1981), was used to approximate the extent of water less than about 10 feet deep in the Great Salt Lake Desert. Where the mud flats extend beyond the mapped brine region, particularly along the east edge, ground water may also be within 10 feet of the ground surface. In the north half of the desert, previously mapped areas of "bare soil with water table less than 10 feet below the land surface" (Stephens, 1974a) provided a basis for locally extending the brine-based line. The spring-fed marshes and mud flats of Fish Springs Flat are also likely to have shallow ground water and thus were included within the 10-foot contour. In general, there was insufficient depth-to-water information and topographic control on the basin margins to verify the distribution of the shallowest ground water or to delineate surrounding areas of water less than 30 feet deep. A zone of mapped phreatophytes bordering the northwest corner of the mud flats (Stephens, 1974a) provided a basis for drawing the 30-foot contour northeast of Pilot Valley. Other areas of shallow ground water, not shown on the map, are evidenced by narrow, isolated bands of phreatophytes that have been mapped along the bases of mountains.

Valleys South of the Great Salt Lake Desert

Shallow ground water occurs in alluvial and lacustrine deposits within the central portions of Snake, Deep Creek, and Tule Valleys. Phreatophytes in these basins have been mapped and linked with ground-water depths less than about 40 to 50 feet (Hood and Rush, 1965; Hood and Waddell, 1969; Stephens, 1977), and thus served to identify the areas of generally shallow ground water. Bare soil areas and phreatophyte assemblages with depth-to-water associations of 2 to 10 feet (0.6-3.0 m) provided the basis for delineating the 10-foot contours. The shallowest water areas consist of meadow-type vegetation and small spring-fed playas in Snake Valley, flood plains in Deep Creek Valley, and playas, marshes, and spring areas in Tule Valley. Shallow well data were used to check phreatophyte-based mapping, but such data points were too few in any of the basins to provide much control. A 50-foot water-depth contour drawn by Fugro National, Inc. (1979) from sparse data for the Ferguson Desert portion of Snake Valley generally follows the margin of mapped phreatophytes, except northwest of the Burbank Hills where it extends beyond the phreatophytes to the range front.

Ground water shallow enough to support phreatophyte growth in Pine and Wah Wah Valleys occurs only in isolated perched zones in mountain valleys (not mapped). Water beneath the central portions of these two basins is generally hundreds of feet deep (Stephens, 1974b, 1976).

Sevier Desert

Ground water is shallow throughout most of the lake-bottom deposits of the Sevier Desert. Confining layers at shallow depths generally separate the shallow water table from underlying artesian systems (Mower and Feltis, 1968). Phreatophyte mapping provided the basis for defining the distribution of shallow ground water over much of the desert (Mower, 1965; Mower and Feltis, 1968). However, a lack of phreatophyte or other shallow ground-water information along the Beaver River between Clear Lake and Black Rock required interpolation based on topography. Similarly, a lack of data around Sevier Lake necessitated defining the extent of shallow ground water on the basis of topography and the current high lake level. In places, the modern shoreline of Sevier Lake may more closely correspond to the boundary of shallow ground water than to the lake outline shown on the base map. In the areas of the Sevier Desert where natural vegetation has been removed, notably within the agricultural land near Delta and in Pavant Valley (southeastern Sevier Desert), the likely extent of shallow ground water was inferred from well data and the surrounding distribution of phreatophytes.

In Pavant Valley, shallow ground water was identified beyond the limits of phreatophyte growth using water levels from shallow wells and the distribution of flowing wells (Mower, 1965). Ground-water levels in Pavant Valley have fluctuated substantially since these data were collected, however. The first decade of significant pumping, beginning in the early 1950s, coincided with a period of below-normal precipitation, causing average water-level declines in wells of 8 feet (2.4 m) beneath the entire valley and 16 feet (4.9 m) beneath the area of pumped wells, and causing a decrease in the area of flowing wells (Mower, 1965). In the two decades since compilation of the phreatophyte and well data, overall precipitation has been above average and water levels have risen (Gates, 1985). Because of the increase in recharge since the data were collected, shallow ground water may be more widespread than depicted on the map and may be less than 10 feet deep throughout a large portion of the valley. Even in the early 1960s, the water table in the lowest areas was reported to be at or near the land surface (Mower, 1965). The data were insufficient, however, to define a 10-foot ground-water contour for the valley.

The increase in precipitation in recent years has affected shallow ground-water conditions in the rest of the Sevier Desert as well. High-altitude photography (1:54,000 scale) taken in 1984 and a field check by the authors in 1986 indicate persistent surface flooding within portions of the flat desert floor near the Sevier River, beyond areas that in 1963 were covered by phreatophyte species associated with water less than about 10 feet deep (Mower and Feltis, 1968). Elsewhere, recent field checks indicate that phreatophyte areas have not changed significantly since the early 1960s (Holmes, 1984). The areal distribution of shallowest-water phreatophytes (Mower and Feltis, 1968) was used in combination with surface flooding to delimit areas of the Sevier Desert where water depths are probably less than 10 feet. Included were lowland areas between the northeast end of Sevier Lake and extensively flooded reaches of the Sevier and Beaver Rivers. Within the area of cultivated land in the vicinity of Delta, there was insufficient water-table information to delimit a 10-foot contour. However, water has been found at depths less than 10 feet within several miles of Delta (Fisk and Clyde, 1981; J.B. Finlinson, Millard County Health Dept., oral communication, March, 1986), and it is likely that shallow ground water occurs throughout the area.

Shallow ground water also occurs in valleys separated from the Sevier Desert by the Pavant Range and Canyon Mountains. A map of water-table depths and potentiometric-surface depths based on well data (Bjorklund and Robinson, 1968) was modified to map shallow ground water in valleys of the lower Sevier River drainage area near Scipio, Scipio Lake, Mills, and Juab. Areas with water less than 10 feet deep were taken directly, but areas underlain by water at depths less than about 30 feet were interpolated from 10- and 50-foot contours.

Escalante Desert

Shallow ground water is widespread in alluvium which serves as the principal, largely unconfined ground-water aquifer in the Escalante Desert. The Escalante Desert is part of the Beaver River drainage area, but flood water in the Beryl-Enterprise area is generally ponded in low areas and closed depressions on the valley floor and does not exit the basin. The 10-foot ground-water contours reflect the locations of these low areas. Ground-water contours in the Beryl-Enterprise area are based primarily on depth-to-ground-water maps (Fugro National, Inc., 1981a, 1981b) and are supplemented with well data from March 1978 (Mower, 1981, 1982). The well data were used to verify the Fugro National, Inc. maps and to extend the 30-foot contour to the south. In the area south of Milford, ground-water contours were taken directly from Fugro National, Inc. (1981b). From Milford north to Black Rock, ground-water depths were contoured from well data from a number of years (Mower and Cordova, 1974). Except southeast of Black Rock, well control in the area is generally good. Depth-to-ground-water maps from an earlier publication (Sandberg, 1966) were also used in the area around Milford.

The most significant changes in ground-water levels in the Beryl-Enterprise area of the Escalante Desert have occurred in the south part of the basin, north of Enterprise. Here, ground-water withdrawals related to pumping for irrigation have increased fairly steadily since the 1920s, creating a cone of depression and lowering the water table by as much as 70 feet (21.3 m) near the center of the cone (Mower, 1982). A depth-to-water map prepared in 1932 based on phreatophyte growth shows that shallow ground water once occurred in this area (White, 1932).

The Milford area experienced lowering of ground-water levels from the early 1950s to the middle 1960s, due mostly to increases in pumping necessary to offset decreases in precipitation and streamflow (Mower and Cordova, 1974). Ground-water withdrawal has caused minor ground subsidence and cracking near Milford (Mower and Cordova, 1974). Water-level declines continued during the 1970s to the early 1980s, although at a lower rate than that of previous decades. Water levels rose significantly between 1983 and 1985 due to increased precipitation and flow in the Beaver River but have since been declining (J.L. Mason, U.S. Geological Survey, written communication, May, 1987).

Beaver Valley

Shallow ground water occurs in the spring-fed, marshy lowlands of Beaver Valley and along Indian Creek southwest of Manderfield. Local perched ground water (not mapped) occurs approximately 3 miles (5 km) southwest of Beaver, as well as along North Creek (Mower, 1978). Phreatophytes are abundant in Beaver Valley and indicate ground-water depths from 5 to 20 feet below the surface (Mower, 1978).

Ground-water contours were interpolated from a depth-to-water map prepared from well data (Sandberg, 1966). The contours were modified in the Manderfield area to include areas of phreatophytes mapped by Mower (1978). Observation-well measurements taken since 1935 show that ground-water levels have remained fairly constant (Sandberg, 1966; Mower, 1978), suggesting that contours shown on the map may reflect current ground-water levels.

Parowan and Cedar Valleys

Ground water in Parowan and Cedar Valleys (in Iron County) occurs in alluvial deposits in both confined and unconfined systems and as local, shallow perched water (Bjorklund and others, 1978). The shallow ground-water contours generally reflect potentiometric surfaces of confined ground water rather than the actual unconfined water table (Bjorklund and others, 1977, 1978). However, it appears that leakage through confining beds has caused the two levels to be essentially the same. The 10-foot contours incorporate areas of flowing wells in Parowan Valley and water levels less than 10 feet below the surface in Parowan and Cedar Valleys. In both valleys, the 30-foot contours were interpolated from a water-level category in which depths to water range from 10 to 50 feet. A phreatophyte map of the valleys (Bjorklund and others, 1978) generally follows these interpolated 30-foot contours. Well control is poor along the west side of Cedar Valley, and thus the 30-foot contour was not extended into this area.

Measurements in wells since the 1930s reveal a significant overall decline in ground-water levels in the two valleys, due chiefly to increased pumping for irrigation combined with below-average precipitation (Bjorklund and others, 1978). From the early 1960s to the present, however, water levels have generally risen as a probable result of above-average precipitation (Appel and others, 1983). Ground-water levels plotted from mid-1970s well data are somewhat lower than at present, given the subsequent increase in water levels.

Virgin River Drainage Area

Areas of shallow ground water are present in many canyons and stream valleys in the southwest corner of Utah. Shallow ground water commonly occurs where incised stream valleys intersect the regional water table and water discharges into the alluvium (figure 3a) or where less permeable bedrock maintains local ground water in the overlying alluvium (figure 3b). Much of the shallow ground water supports seepage to streams and phreatophytes along stream channels (Cordova, 1981; Cordova and others, 1972).

Water-level data and maps showing areas of phreatophytes and "areas of thick unconsolidated rocks containing aquifers" within the largest valleys were used to derive 30-foot water-depth contours for the Virgin River area (Cordova, 1981; Cordova and others, 1972).

Water levels in wells completed in the alluvial aquifers and topographic relief adjacent to valley floors further constrained the distribution of mappable shallow ground water. The extent of water less than about 30 feet deep has been established by shallow-well and auger-hole data for the St. George and Washington areas (Cordova and others, 1972; Utah Geological and Mineral Survey and Utah Division of Water Rights unpublished data). Most of the unconsolidated deposits are saturated to variable but shallow depths. Unconsolidated deposits covering the Santa Clara Bench near Ivins overlie an undulating bedrock topography and contain ground water only where thickest (Cordova, and others, 1972). An isolated body of water less than 30 feet deep was defined in the vicinity of Ivins on the basis of phreatophytes and a few wells. Although phreatophytes occur in most valleys of the Virgin River and its tributaries, only the largest shallow ground-water areas could be shown at the small scale of the map.

The region to the west of the Hurricane Cliffs (Pine Valley Mountains area) contains several alluvial valleys with shallow water tables. The areal extent of shallow ground water could not be shown on the map, however, because valley margins are not distinct and wells are either scarce or located only along drainageways. Ground water less than 30 feet deep has been recorded in four basin areas in the region around Pine Valley and New Harmony (Cordova and others, 1972).

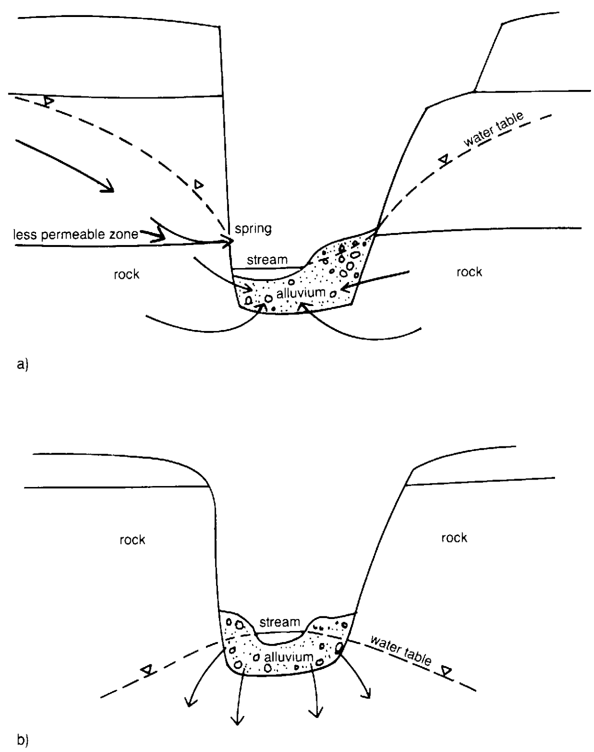

Figure 3. Schematic cross sections of ground-water conditions in incised stream valleys of southwestern Utah and the Canyonlands of the Colorado Plateau. Shallow ground water may be maintained by a) discharge from bedrock aquifers to valley alluvium, or b) stream flow recharge to alluvium.

COLORADO PLATEAU

The Colorado Plateau is characterized by horizontal to gently dipping sedimentary rocks. Shallow ground water occurs principally at the north and west ends of the region in the Uinta Basin and High Plateaus, respectively. Elsewhere, unconsolidated deposits are generally thin and do not contain ground water except along major streams. Over much of the Plateau, the regional water table is hundreds of feet deep and shallow only along stream flood plains in the bottoms of narrow, deeply incised canyons. Local zones of perched water are common throughout the region. There are numerous areas too small and/or with too little data to show on the map where irrigation may contribute to shallow ground-water tables. Many of these areas occur on stream flood plains near population centers. Maps depicting irrigated areas in the Colorado River Basin (Iorns and others, 1965) are useful in identifiying areas of possible shallow ground water where data are lacking.

Canyonlands

Unconsolidated deposits in the large Canyonlands region of Utah are generally confined to alluvium, commonly saturated, in narrow canyon bottoms (figure 3) and to thin mantles of gravel, sand, and wind-blown silt (loess) on plateau surfaces. Because of the lack of both well data and unconsolidated deposits, shallow ground water is shown on the map only within Spanish Valley (Moab area, Grand County), locally within the Kanab Creek drainage basin, and along the San Juan River.

Many shallow wells in Spanish Valley are completed in the unconsolidated alluvium which fills the valley to depths of over 360 feet (109.7 m) (Sumsion, 1971). Contours were drawn using water depths in shallow wells recorded at the time the wells were drilled (Sumsion, 1971). The water table is shallow toward the lower parts of the valley where phreatophytes grow and marshy conditions exist adjacent to the Colorado River. Alluvial deposits in southeastern Spanish Valley also contain ground water, but well data indicate depths to water greater than 30 feet. Castle Valley, northeast of Spanish Valley, contains unconfined ground water in alluvial fill. However, based on data from a few wells (Weir and others, 1983), it appears that ground water is greater than 30 feet deep, except adjacent to the valley's main stream, Castle Creek. Fisher Valley, located northeast of Castle Valley, may also contain shallow ground water within alluvial fill, but no data are available to indicate actual depths.

Mappable shallow ground water occurs in alluvium along streams in the southwest corner of the region. Numerous wells clustered at the south end of Johnson Canyon, east of Kanab (Cordova, 1981), define at least part of an area where water depths in alluvium are close to 30 feet. Information from wells in unconsolidated deposits around tributary streams north of Johnson Canyon indicates perched water at depths less than 40 feet (Cordova, 1981). Phreatophyte mapping provides evidence for shallow ground water within a central reach of Johnson Canyon and along a wash tributary to upper Kanab Creek (Cordova, 1981).

Ground water at depths less than 30 feet is present beneath the flood plain of the San Juan River (Cooley and others, 1983). Well data indicate that there is also ground water less than 10 feet (Avery, 1986), but a lack of wells in the area precluded drawing ground-water contours from these data. The 30-foot contour was drawn using a generalized phreatophyte map (Whitfield and others, 1983).

Other areas in Canyonlands locally contain shallow ground water (not mapped) along river flood plains or perched at the contact between surficial unconsolidated materials and underlying bedrock, usually Mancos Shale. Such perched ground water likely exists in many areas around Price, where data from eight drill holes show that ground-water levels beneath the Price River flood plain in southern Price average approximately 5 feet deep (Powell, 1974). The flood plain in this area is irrigated, and this likely contributes to a high ground-water table. Irrigation and recharge from canals have also created areas of shallow ground water in generally thin slope wash and pediment deposits surrounding the towns of Ferron and Huntington (Price and Arnow, 1974; B. L., Everitt, Utah Department of Water Resources, written commununication, June 1987). Irrigation along approximately 10 miles (16 km) of the flood plain of the Green River probably sustains a shallow ground-water table at and north of the city of Green River, but data are insufficient to draw ground-water contours. Ground water occurs in alluvium near the towns of Blanding and LaSal and in alluvium and the upper part of the underlying Dakota Sandstone east of Monticello (Lofgren, 1954). Wells in these areas, however, indicate depths to ground water exceeding 100 feet.

Uinta Basin

Shallow ground water in the Uinta Basin occurs mainly north of the Duchesne River. Unconfined and perched ground-water conditions are widespread in glacial outwash, alluvium, and in gravel terraces and gravel-mantled pediments in this area (Hood and Fields, 1978). Bedrock crops out extensively south of the Duchesne River, where there are few unconsolidated deposits and little shallow ground water.

Ground-water contours for the Uinta Basin are based primarily on compiled well data (Hood and others, 1976; Hood, 1977a; Hood, 1977b). In the Ashley Valley area, contours were drawn using April 1950 measurements from shallow observation wells. The remaining areas of the basin reflect ground-water levels measured at the time the wells were drilled, encompassing data from the late 1940s to early 1970s. Although primarily based on shallow well data, the 30-foot contour lines are approximately located because very few wells completed in unconsolidated materials with water levels greater than 30 feet are available to constrain the contours. Where necessary, the 30-foot contours were refined by considering the contact between unconsolidated deposits and bedrock, topographic influences, and seepage contribution from canals.

Glacial outwash mantles large areas adjacent to the Lake Fork River and canal system in Duchesne County, south of canyon mouths near Whiterocks River in Uintah County, and along the Uinta River in both counties. Ground-water depths in these deposits are generally less than 30 feet but are locally less than 10 feet near the towns of Altamont, Mt. Emmons, and Mountain Home. The northernmost boundaries of the 30-foot contours are based on well data (Hood and others, 1976) and the areal extent of unconsolidated deposits. The contours were further refined by considering the probable influence of seepage from canals. For example, north of Mountain Home and Altonah, the 30-foot contour closely follows the Farnsworth and Yellowstone Feeder canals.

Shallow ground water also occurs in alluvial deposits along the flood plains of the Duchesne, Lake Fork, Ashley, and Green Rivers, and along the lower reaches of Dry Gulch Creek and the White River. Ground water in these areas is generally less than 30 feet and becomes more shallow with proximity to stream channels. Although not quantitatively assessed, canal leakage has been documented along banks of the Duchesne River between Duchesne and Myton (Cruff and Hood, 1976) and likely contributes to the shallow water table.

Extensive alluvial deposits exist along the channels and interfluves of the middle to lower reaches of the Uinta River and its tributaries. Ground water in this area is generally less than 30 feet but varies locally. A lack of well data precluded drawing a 10-foot contour, although ground water is within 10 feet of the surface at many localities, including lands surrounding the towns of Ballard (east of Roosevelt) (Christenson, 1981), Hayden, and Bennett (northeast of Roosevelt).

In Ashley Valley, the 30-foot contour conforms to the contact between unconsolidated deposits and bedrock. Well data show that a substantial portion of the valley contains water within 10 feet of the ground surface (Hood, 1977a). Ground-water fluctuations occur mainly through changes in the rate of surface-water seepage from canals and irrigated areas along the west side of the valley (Hood, 1977a). Since the completion of Steinaker Reservoir in 1963 and associated diversion of former streamflow into canals, ground-water levels below the dam have risen (Hood, 1977a). However, comparison of water levels in five wells from 1948 to 1974 have shown that these changes are not sufficient to warrant altering ground-water contours (Hood, 1977b). Thus, the 1950s well data used to draw ground-water contours are considered representative of current conditions.

Shallow ground water also occurs under gravel surfaces, river terraces, and debris-mantled pediments along the lower reaches of the Lake Fork River, along the Duchesne River northeast of Bridgeland in Duchesne County, and surrounding Pelican Lake near Leota in Uintah County. Well data indicate many areas of ground water less than 10 feet, but depths of 15 to 20 feet are also common. The 30-foot contour includes these areas, with outer margins of the contour conforming to the bedrock contact and topography.

High Plateaus

The High Plateaus is a region of high-elevation tablelands separated by several north-trending structural valleys. The parallel, flat-bottomed alluvial valleys, mainly of the Sevier River and its major tributaries, contain shallow ground water throughout their lengths.

The major stream valleys consist of distinct ground-water basins separated by bedrock constrictions where the valleys narrow. Within the upper portions of these basins, ground water in alluvium is generally unconfined and is recharged from streamflow. Bedrock constrictions at the lower ends of the basins restrict the flow of ground water, forcing water to the surface through fine-grained confining layers. As a result, areas under artesian pressure upvalley of the constrictions are characterized by springs, seeps, marshes, and meadowlands. Ground water is also discharged to ditches cut to drain the saturated flood-plain deposits (Carpenter and others, 1967; Robinson, 1971; Young and Carpenter, 1965). The valleys thus consist of alternating ground-water recharge and discharge areas, with shallowest water occurring upstream from valley constrictions.

Mapped areas of phreatophyte growth and flowing wells indicate shallow ground water in the valleys along Otter Creek and along the Sevier, East Fork Sevier, and San Pitch Rivers (Carpenter and others, 1967; Robinson, 1971; Young and Carpenter, 1965). Flat valley floors, springs, marshes, oxbow lakes, and shallow wells occur in zones defined by phreatophytes and flowing wells and thus indicate that corresponding water depths are probably 10 feet or less.

Maps of phreatophytes and potentiometric surface depths along the San Pitch River (in Sanpete Valley) (Robinson, 1971) supplied sufficient information to delineate both 10- and 30-foot ground-water contours. Mapped wet meadow vegetation generally covers the same areas as flowing wells and wells that record potentiometric surfaces less than 10 feet deep. Restricted areas of deeper-water phreatophytes were used to locally extend areas bordering the valley where potentiometric surfaces vary from 10 to 30 feet deep. Although potentiometric surfaces may be higher than the water table, ground-water levels along the San Pitch River have risen since the data were collected, and thus the potentiometric contours may approximate present water-table depths. Mount Pleasant, near the north end of the valley, is one community that experienced basement flooding in the years of increased precipitation beginning in 1982 (Christenson, 1985b).

Shallow ground water occurs under both confined and unconfined conditions in alluvial deposits along the upper Fremont River, a tributary to the Dirty Devil and Colorado Rivers, near the towns of Fremont, Loa, Lyman, and Bicknell. Artesian conditions occur within alluvium at and southeast of Fremont and south of Bicknell in Bicknell Bottoms. Both areas support abundant phreatophytes. However, Bicknell Bottoms serves as the major discharge zone for water moving through the valley fill (Bjorklund, 1969). The upper Fremont River valley is irrigated, and ground-water levels fluctuate with seasonal leakage from irrigation canals (Hood and Danielson, 1981). Perched ground-water conditions (not mapped) exist southeast of Loa and are thought to result from irrigation and stream seepage from the Fremont River and Roads Creek (Bjorklund, 1969). Bjorklund (1969) mapped ground-water depths based on data from over 60 wells in the region. The 10-foot ground-water contours were taken directly from Bjorklund (1969), and the 30-foot contours were interpolated from a 10- to 50-foot water-depth category on the same map.

MIDDLE ROCKY MOUNTAINS

The Middle Rocky Mountains physiographic province in northeastern Utah chiefly consists of the Wasatch Range, the Bear River Range, the Uinta Mountains, and intervening valleys. Shallow ground water in the region occurs around alpine lakes and in meadows, along numerous streams, and in several broad, flat intermountain valleys.

Shallow ground water is common in the Wasatch Range back valleys along and tributary to the Weber and Provo Rivers. Much of the valley alluvium is saturated to within a few feet of the surface, and ground water discharges to surface drainages and supports ponds, sloughs, marshy bottomlands, and phreatophytes (Baker, 1970; Gates and others, 1984; Gill and Lund, 1984; Holmes and others, 1986; Saxon, 1972). Shallow ground water was delineated for most of the intermountain valleys using well data and topography (Baker, 1970; Gates and others, 1984; Holmes and others, 1986). In addition, mapping of alluvium greater than about 10 feet thick provided a limit for mappable shallow ground water near Henefer and in Morgan Valley (Gates and others, 1984). Shallow ground water in Ogden Valley was identified from soil survey data (Carley and others, 1980) and delineated by soil mapping and topography. Field observations of standing water (H.E. Gill, Utah Geological and Mineral Survey, oral communication, 1985) provided the basis for defining shallow ground water in an area 3 miles (5 km) northwest of Keetley. The section of the Weber River Valley between Morgan and Wanship may have shallow ground water but, except near Henefer, data are lacking.

Maps showing depths to shallow water have been published for the Park City area (Gill and Lund, 1984) and for Heber Valley (Baker, 1970). Ground water less than about 10 feet deep occurs in the valley areas east (Deer Valley) and north of Park City and in essentially all but the south-central portion of Heber Valley (Baker, 1970). South-central Heber Valley is somewhat anomalous in that it has relatively deep water (greater than 100 feet) which is apparently unrelated to topography or pumping (Baker, 1970; Fisk and Clyde, 1980). Water less than 5 feet deep characterizes much of the west half of the valley.

The upper Bear River and Bear Lake areas, east of the Bear River Range, lack well data and phreatophyte mapping, and thus the distribution of shallow ground water was estimated principally from topography and distribution of marshes. Ground water in the central portion of the upper Bear River Valley averages about 20 to 30 feet deep (Haws and Hughes, 1973), although the abundance of wetland areas suggests that depths less than 10 feet are common. Water is shallow enough (generally less than 10 feet) to flood septic-tank soil-absorption fields in the Bear River Valley between Sage Creek Junction and Woodruff and along the west side of Bear Lake between Garden City and Pickleville (Fisk and Clyde, 1981).

Shallow ground water occurs around lakes and along streams in the high alpine terrain of the Uinta Mountains. The largest areas of shallow ground water are probably found near the crest of the mountains in the flat-bottomed headwater areas of glaciated valleys. However, there is little information from which to define the distribution of shallow ground water in this region, and most occurrences are isolated and probably too small to map.

SHALLOW GROUND-WATER HAZARDS

Shallow ground water is found in many of Utah's urban areas and has had a variety of adverse effects on urban development. The frequency and severity of shallow ground-water problems have increased with recent record-breaking, above-average precipitation. The principal impact of shallow ground water on development has been flooding of basements, underground utilities and storage facilities, septic-tank soil-absorption fields, and landfills and other waste dumps. In some cases, rising water levels have resulted in local ground-water contamination and movement of contaminants into other subsurface facilities and into surface waters, causing health and safety problems. Although shallow ground water is generally not important for water supply, under certain conditions contaminated shallow ground water may mix with water in underlying aquifers and degrade the quality of drinking and irrigation water.

The need to consider shallow ground-water hazards prior to development is evident from the extent of ground-water flooding in some areas. Significant basement and septic-tank-system flooding has recently occurred in Riverton, South Jordan, Sandy, and Rose Park (Salt Lake County); Ballard (Uintah County); Plymouth (Box Elder County); Erda, St. John, and Clover (Tooele County); and Fountain Green, Mt. Pleasant, and Ephraim (Sanpete County). Isolated occurrences of such flooding are common in many other areas of the state. Shallow ground water is important even in areas served by sanitary sewer systems because it infiltrates sewer lines, requiring additional water-treatment-plant capacity. Landfills flooded by ground water near Great Salt Lake in Davis and Salt Lake Counties have posed potential leachate contamination problems to the lake and surrounding area. Recent rising water tables in the Wasatch Front area have carried gasoline from leaking underground storage tanks into sewer lines. Gasoline fumes entering buildings through these lines have presented a health and safety hazard, necessitating evacuation of buildings in Rose Park, Salt Lake City, and West Valley City. Gasoline in shallow ground water has also been reported in Sugar House, Moab, Kaysville, and many other communities, particularly along the Wasatch Front. Other types of localized contamination have also occurred from mill tailings, mine waste dumps and evaporation ponds, and various hazardous-waste dumps.

Shallow ground water may also pose hazards to foundations and transportation facilities during and after construction. Excavations in shallow ground-water areas must often be de-watered during construction because water decreases cut-slope stability and makes working conditions difficult. Saturation reduces soil bearing strength, particularly in fine-grained soils, and may weaken foundations or cause deterioration of highways and airport runways.

Measures to mitigate shallow ground-water hazards can be implemented either before or after development (construction) but are generally less expensive if considered during the planning stage. Correcting shallow ground-water problems such as flooding, contamination, or destabilization can be costly. Flooding of homes is best avoided through the use of slab-on-grade construction, but basements are possible in shallow ground-water areas if properly sealed, drained, or pumped. Septic-tank systems flooded by ground water will not operate properly and may contaminate both surface and ground water. As a result, conventional systems are generally not allowed in areas where the highest level of the water table is within 4-5 feet of the surface. Because this restricts development in rural areas not served by sewer systems, alternative individual waste-water disposal systems are being considered by the Utah Department of Health for use in shallow ground-water areas. Awareness of potential ground- and surface-water contamination has prompted some local governments to restrict the use of septic-tank systems in shallow ground-water areas near reservoirs to protect public water supplies and recreational values. Problems related to contamination of shallow ground water by toxic-waste materials (landfills and chemical, mine, or radioactive wastes) are best avoided by considering the ground-water hydrology in the siting of waste dumps. Clean-up and containment of contaminated water are difficult and expensive and generally involve pumping and/or placement of impermeable barriers such as slurry walls to impede the flow of ground water.

In areas of high earthquake potential, such as the Wasatch Front, shallow ground water in loose silty and sandy soils may pose a hazard known as liquefaction. Liquefaction may occur as a result of ground shaking during earthquakes of approximate Richter magnitude 5.0 and larger (Kuribayashi and Tatsuoka, 1975, 1977; Youd, 1977) and may cause cracking, tilting, or settlement of buildings and failure of slopes with gradients as low as 0.5 percent (Anderson and others, 1982, 1986a, 1986b). Geologic evidence suggests that in about the last 20,000 years (during and after the time of Lake Bonneville) liquefaction-induced slope failures (lateral spreads) have occurred over several square miles in Weber, Davis, Salt Lake, and Utah Counties (Van Horn, 1975; Miller, 1980, 1982). Recent studies along the Wasatch Front have delineated large areas of high liquefaction potential which roughly coincide with areas where ground water is less than 10 feet deep (Anderson and others, 1982, 1986a, 1986b). Structures most susceptible to damage caused by liquefaction are buildings with shallow foundations, highways, railways, bridges, and dams. Engineering techniques to mitigate liquefaction hazards include removal of susceptible materials, densification, grouting, dewatering, and use of deep pile foundations (National Research Council, 1985).

CONCLUSIONS AND RECOMMENDATIONS

Water tables less than 30 feet deep in unconsolidated deposits are found in approximately 15 percent of the state. Shallow water tables are prevalent in the alluvium of major stream valleys in central Utah and in the alluvial and lacustrine basin fill of western Utah. The largest areas of shallow ground water occur in northwestern Utah around Great Salt Lake and in the Great Salt Lake Desert, where water is generally less than 10 feet deep. Shallow ground water is also extensive in the Sevier Desert to the south and in central basin areas throughout the Basin and Range. Ground water is similarly shallow in the stream valleys of the Rocky Mountains (e.g., Bear River, Ogden, Morgan, Kamas, and Heber Valleys) and High Plateaus (mainly valleys of the Sevier River drainage basin). Shallow ground water is largely absent in the Colorado Plateau region of eastern Utah, except in the northern Uinta Basin.

Shallow water tables are not static, but fluctuate in response to changes in precipitation, irrigation, and/or pumping. Since 1982, significant increases in shallow water tables have probably occurred locally in response to above-average precipitation and resulting increases in surface-water infiltration and flow from underlying artesian aquifers. Long-term trends in ground-water levels cannot be predicted, however, and the contours shown on the map represent a composite of varying water levels from the last 30 to 40 years. The map does not depict the highest expected ground-water levels, but it does generally indicate all major areas in Utah where ground water is shallow enough to present a hazard to development.

Most problems caused by shallow ground water can be mitigated or avoided once the hazard is known and understood. The greatest difficulty in dealing with shallow ground-water hazards is predicting the highest levels to which water tables may rise. This step is important in evaluating the suitability of an area for basements, septic-tank soil-absorption fields, or any type of waste-disposal site. In most areas, the data needed to identify and address shallow ground-water hazards has not been collected. Existing information in most areas is sparse, of uneven quality, and sufficiently detailed to illustrate and describe only the general patterns of shallow ground-water occurrence. Thus, the accompanying map and text are only a preliminary step in identifying areas of shallow ground water and are meant to alert communities to the potential for problems. As a regional compilation, the information presented should be used by local governments and the private sector as a basis for identifying where shallow ground water may exist and where site-specific, planning-related studies may be advisable prior to development. The potential for shallow ground-water-related problems is considered generally highest in areas within the 10-foot depth-to-water contours. However, areas enclosed by the 30-foot contours may have the potential for liquefaction or may include areas where water, at least periodically, is less than 10 feet deep. Recognizing the presence of shallow ground water and taking precautions to mitigate the potential hazards can minimize the subsequent need for costly corrective measures to deal with flooding, contamination, and foundation problems.

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SELECTED REFERENCES

Anderson, L.R., Keaton, J.R., Aubry, Kevin, and Ellis, S.J., 1982, Liquefaction potential map for Davis County, Utah: Prepared by Utah State University Department of Civil and Environmental Engineering and Dames and Moore Consulting Engineers for U.S. Geological Survey, Contract No. 14-08-0001-19127, 50 p.

Anderson, L.R., Keaton, J.R., and Bischoff, J.E., 1986a, Liquefaction potential map for Utah County, Utah: Prepared by Utah State University Department of Civil and Environmental Engineering and Dames and Moore Consulting Engineers for U.S. Geological Survey, Contract No. 14-08-0001-21359, 46 p.

Anderson, L.R., Keaton, J.R., Spitzley, J.E., and Allen, A.C., 1986b, Liquefaction potential map for Salt Lake County, Utah: Prepared by Utah State University Department of Civil and Environmental Engineering and Dames and Moore Consulting Engineers for U.S. Geological Survey, Contract No. 14-08-0001-19910, 48 p.

Appel, C.L., Herbert, L.R., Bischoff, D.A., Smith M.E., Seiler, R.L., Suttormson, Kevin, Jensen, V.L., Enright, Michael, Emett, D.C., Burden, Carole, Beard, R.C., Sultz, L.G., Eckenwiler, M.R., and Sandberg, G.W., 1983, Developing a state water plan, ground-water conditions in Utah, spring of 1983: Utah Division of Water Resources Cooperative Investigations Report Number 23, 96 p.

Avery, Charles, 1986, Bedrock aquifers of eastern San Juan County, Utah: Utah Department of Natural Resources Technical Publication 86, 114 p.

Baker, C.H., Jr., 1970, Water resources of the Heber-Kamas-Park City area, north-central Utah: Utah Department of Natural Resources Technical Publication 27, 79 p.

Bedinger, M.S., Gates, J.S., and Stark, J.R., 1984a, Maps showing ground-water units and withdrawal, Basin and Range Province, Utah: U.S. Geological Survey Water-Resources Investigations Report 83-4122-A, scale 1:500,000.

Bedinger, M.S., Mason, J.L., Langer, W.H., Gates, J.S., Stark, J.R., and Mulvihill, D.A., 1984b, Maps showing ground-water levels, springs, and depth to ground water, Basin and Range Province, Utah: U.S. Geological Survey Water-Resources Investigations Report 83-4122-B, scale 1:500,000.

Bjorklund, L.J., 1967, Ground-water resources of northern Juab Valley, Utah: Utah State Engineer Technical Publication 17, 69 p.

———1969, Reconnaissance of the ground-water resources of the upper Fremont River valley, Wayne County, Utah: Utah Department of Natural Resources Technical Publication 22, 54 p.

Bjorklund, L.J., and McGreevy, L.J., 1971, Ground-water resources of Cache Valley, Utah and Idaho: Utah Department of Natural Resources Technical Publication 36, 72 p.

———1974, Ground-water resources of the lower Bear River drainage basin, Box Elder County, Utah: Utah Department of Natural Resources Technical Publication 44, 65 p.

Bjorklund, L.J., and Robinson, G.B., Jr., 1968, Ground-water resources of the Sevier River Basin between Yuba Dam and Leamington Canyon, Utah: U.S. Geological Survey Water-Supply Paper 1848, 79 p.

Bjorklund, L.J., Sumsion, C.T., and Sandberg, G.W., 1977, Selected hydrologic data, Parowan Valley and Cedar City Valley drainage basins, Iron County, Utah: U.S. Geological Survey in cooperation with Utah Division of Water Rights, Utah Basic-Data Release 28, 55 p.

———1978, Ground-water resources of the Parowan-Cedar City drainage basin, Iron County, Utah: Utah Department of Natural Resources Technical Publication 60, 93 p.

Bolke, E.L., and Price, Don, 1969, Hydrologic reconnaissance of Curlew Valley, Utah and Idaho: Utah Department of Natural Resources Technical Publication 25, 40 p.

———1972, Hydrologic reconnaissance of the Blue Creek Valley area, Box Elder County, Utah: Utah Department of Natural Resources Technical Publication 37, 38 p.

Bolke, E.L., and Sumsion, C.T., 1978, Hydrologic reconnaissance of the Fish Springs Flat area, Tooele, Juab, and Millard Counties, Utah: Utah Department of Natural Resources Technical Publication 64, 30 p.

Bolke, E.L., and Waddell, K.M., 1972, Ground-water conditions in the East Shore area, Box Elder, Davis, and Weber Counties, Utah, 1960-69: Utah Department of Natural Resources Technical Publication 35, 59 p.

Carley, J.A., Jensen, E.H., Campbell, L.B., Barney, Marvin, Fish, R.H., Chadwick, R.S., and Winkelaar, Paul, 1980, Soil survey of Morgan area, Utah-Morgan County and eastern part of Weber County: U.S. Soil Conservation Service in cooperation with Utah Agricultural Experiment Station, 300 p.

Carpenter, C.H., Robinson, G.B., Jr., and Bjorklund, L.J., 1967, Ground-water conditions and geologic reconnaissance of the upper Sevier River basin, Utah: U.S. Geological Survey Water-Supply Paper 1836, 91 p.

Christenson, G.E., 1981, Engineering geology for land-use planning, Ballard, Utah: Utah Geological and Mineral Survey Report of Investigation 167, 13 p.

———1985a, Basement flooding by ground water along 11400 South Street, South Jordan, Utah, *in* Harty, K.M., compiler, Technical Reports for 1984 - Site Investigation Section: Utah Geological and Mineral Survey Report of Investigation 198, p. 263-275.

———1985b, Mount Pleasant ground-water study, *in* Harty, K.M., compiler, Technical Reports for 1984 - Site Investigation Section: Utah Geological and Mineral Survey Report of Investigation 198, p. 232-236.

Clark, D.W., 1984, The ground-water system and simulated effects of ground-water withdrawals in northern Utah Valley, Utah: U.S. Geological Survey Water-Resources Investigations Report 85-4007, 56 p.

Clark, D.W., and Appel, C.L., 1985, Ground-water resources of northern Utah Valley, Utah: Utah Department of Natural Resources Technical Publication 80, 115 p.

Cooley, M.E., Harshbarger, J.W., Akers, J.P., and Hardt, W.F., 1969, Regional hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521-A, 61 p.

Cordova, R.M., 1981, Ground-water conditions in the upper Virgin River and Kanab Creek Basins area, Utah, with emphasis on the Navajo Sandstone: Utah Department of Natural Resources Technical Publication 70, 87 p.

Cordova, R.M., Sandberg, G.W., and McConkie, Wilson, 1972, Ground-water conditions in the central Virgin River Basin, Utah: Utah Department of Natural Resources Technical Publication 40, 64 p.

Cruff, R.W., and Hood, J.W., 1976, Seepage study of the Rocky Point Canal and the Grey Mountain-Pleasant Valley canal systems, Duchesne County, Utah: Utah Department of Natural Resources Technical Publication 50, 53 p.

Currey, D.R., Atwood, Genevieve, and Mabey, D.R., 1984, Major levels of Great Salt Lake and Lake Bonneville: Utah Geological and Mineral Survey Map 73, scale 1:750,000.

Feltis, R.D., 1967, Ground-water conditions in Cedar Valley, Utah County, Utah: Utah State Engineer Technical Publication 16, 34 p.

Fisk, E.P., and Clyde, C.G., 1981, A survey and evaluation of shallow ground-water contamination hazards in the state of Utah: Utah Water Research Laboratory Hydraulics and Hydrology Series UWRL/H-81/04, Utah State University, 45 p.

Fix, P.F., Nelson, W.B., Lofgren, B.E., and Butler, R.G., 1950, Ground water in the Escalante Valley, Beaver, Iron, and Washington Counties, Utah (a progress report): Utah State Engineer Technical Publication 6, 210 p.

Fugro National, Inc., 1979, MX siting investigation, geotechnical evaluation, volume III, Nevada-Utah verification studies, FY 79, geotechnical data, Snake East CDP, Utah: Unpublished consultant's report for U.S. Air Force.

———1981a, MX siting investigation, preliminary geotechnical investigation, proposed operational base site, Beryl, Utah, volume I synthesis: Unpublished consultant's report for U.S. Air Force, 33 p.

———1981b, MX siting investigation, preliminary geotechnical investigation,proposed operational base site, Milford, Utah, volume I - synthesis: Unpublished consultant's report for U.S. Air Force.

Gates, J.S., 1985, Utah ground-water resources, *in* National Water Summary 1984, Hydrologic Events, Selected Water-quality Trends, and Ground-water Resources: U.S. Geological Survey Water-Supply Paper 2275, p. 415-420.

Gates, J.S., and Kruer, S.A., 1981, Hydrologic reconnaissance of the southern Great Salt Lake Desert and summary of the hydrology of west-central Utah: Utah Department of Natural Resources Technical Publication 71, 55 p.

Gates, J.S., Steiger, J.I., and Green, R.T., 1984, Ground-water reconnaissance of the central Weber River area, Morgan and Summit Counties, Utah: Utah Department of Natural Resources Technical Publication 77, 70 p.

Gill, H.E., and Lund, W.R., 1984, Engineering geology of Park City, Summit County, Utah: Utah Geological and Mineral Survey Special Studies 66, 42 p.

Haws, F.W., and Hughes, T.C., 1973, Hydrologic inventory of the Bear River study unit: Utah Water Research Laboratory PRWG 40-8, Utah State University, Logan, Utah, 126 p.

Heath, R.C., 1983, Basic ground-water hydrology: U.S. Geological Survey Water-Supply Paper 2220, 84 p.

Hely, A.G., Mower, R.W., and Harr, C.A., 1971, Water resources of Salt Lake County, Utah: Utah Department of Natural Resources Technical Publications 31, 244p.

Holmes, W.F., 1984, Ground-water hydrology and projected effects of ground-water withdrawals in the Sevier Desert, Utah: Utah Department of Natural Resources Technical Publication 79, 54 p.

Holmes, W.F., Thompson, K.R., and Enright, Michael, 1986, Water resources of the Park City area, Utah, with emphasis on ground water: Utah Department of Natural Resources Technical Publication 85, 81 p.

Hood, J.W., 1971, Hydrologic reconnaissance of the Park Valley area, Box Elder County, Utah: Utah Department of Natural Resources Technical Publication 30, 51 p.

———1972, Hydrologic reconnaissance of the Promontory Mountains area, Box Elder County, Utah: Utah Department of Natural Resources Technical Publication 38, 42 p.

———1977a, Hydrologic evaluation of Ashley Valley, northern Uinta Basin area, Utah: Department of Natural Resources Technical Publication 54, 25 p.

———1977b, Hydrologic evaluation of the upper Duchesne River Valley, northern Uinta Basin area, Utah: Utah Department of Natural Resources Technical Publication 57, 34 p.

Hood, J.W., and Danielson, T.W., 1981, Bedrock aquifers in the lower Dirty Devil River basin area, Utah, with special emphasis on the Navajo Sandstone: Utah Department of Natural Resources Technical Publication 68, 143 p.

Hood, J.W., and Fields, F.K., 1978, Water resources of the northern Uinta Basin area, Utah and Colorado, with special emphasis on ground-water supply: Utah Department of Natural Resources Technical Publication 62, 75 p.

Hood, J.W., Mundorff, J.C., and Price, Don, 1976, Selected hydrological data, Uinta Basin area, Utah and Colorado: U.S. Geological Survey in cooperation with Utah Division of Water Rights, Utah Basic-Data Release 26, 321 p.

Hood, J.W., and Price, Don, 1970, Hydrologic reconnaissance of Grouse Creek Valley, Box Elder County, Utah: Utah Department of Natural Resources Technical Publication 29, 54 p.

Hood, J.W., Price, Don, and Waddell, K.M., 1969, Hydrologic reconnaissance of Rush Valley, Tooele County, Utah: Utah Department of Natural Resources Technical Publication 23, 63 p.

Hood, J.W., and Rush, F.E., 1965, Water resources of the Snake Valley area, Utah and Nevada: Utah State Engineer Technical Publication 14, 43 p.

Hood, J.W., and Waddell, K.M., 1968, Hydrologic reconnaissance of Skull Valley, Tooele County, Utah: Utah Department of Natural Resources Technical Publication 18, 57 p.

———1969, Hydrologic reconnaissance of Deep Creek Valley, Tooele and Juab Counties, Utah, and Elko and White Pine Counties, Nevada: Utah Department of Natural Resources Technical Publication 24, 54 p.

Hunt, C.B., 1967, Physiography of the United States: W.H. Freeman and Company, San Francisco, 480 p.

Iorns, W.V., Hembree, C.H., and Oakland, G.L., 1965, Water resources of the Upper Colorado River Basin - technical report: U.S. Geological Survey Professional Paper 441, 370 p.

Kuribayashi, Eiichi, and Tatsuoka, Fumio, 1975, Brief review of liquefaction during earthquakes in Japan: Soils and Foundations, v. 15, no. 4, p. 81-92.

———1977, History of earthquake-induced liquefaction in Japan: Japan Ministry of Construction, Public Works Research Institute Bulletin, v. 31, 26 p.

Lines, G.C., 1979, Hydrology and surface morphology of the Bonneville Salt Flats and Pilot Valley playa, Utah: U.S. Geological Survey Water-Supply Paper 2057, 107 p.

Lofgren, B.E., 1954, Ground-water possibilities of bedrock aquifers in southeastern Utah, *in* Progress Report on Selected Ground-water Basins in Utah: Utah Department of Natural Resources Technical Publication 9, p. 105-118.

Lund, W.R., 1985, Geologic reconnaissance of high groundwater conditions in portions of Ephraim City, Utah, *in* Lund, W.R., editor, Technical Letters and Memoranda for 1983 - Site Investigation Section: Utah Geological and Mineral Survey Report of Investigation 190, p. 190-195.

———1986, Preliminary evaluation of high ground-water conditions in Erda, Tooele County, Utah, *in* Mulvey, W.E., compiler, Technical Reports for 1985 - Site Investigation Section: Utah Geological and Mineral Survey Report of Investigation 208, p. 228-236.

Miller, R.D., compiler, 1980, Surficial geologic map along part of the Wasatch Front, Salt Lake Valley, Utah: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1198, scale 1:100,000.

Miller, R.D., 1982, Surficial geologic map along the southern part of the Wasatch Front,Great Salt Lake and Utah Valleys, Utah: U.S. Geological Survey Miscellaneous Field Investigations Map MF-1477, scale 1:100,000.

Montgomery, S.B., and Everitt, B.L., 1984, Summary of the hydrogeology of Park Valley, Utah, *in* Kerns, G.J., and Kerns, R.L., editors, Geology of Northwest Utah, Southern Idaho, and Northeast Nevada: Utah Geological Association Publication 13, p. 249-259.

Mower, R.W., 1965, Ground-water resources of Pavant Valley, Utah: U.S. Geological Survey Water-Supply Paper 1794, 78 p.

——— 1978, Hydrology of the Beaver Valley area, Beaver County, Utah, with emphasis on ground water: Utah Department of Natural Resources Technical Publication 63, 90 p.

———1981, Ground-water data for the Beryl-Enterprise area, Escalante Desert, Utah: Utah Department of Natural Resources Utah, Hydrologic-Data Report 35, 64 p.

———1982, Hydrology of the Beryl-Enterprise area, Escalante Desert, Utah, with emphasis on ground water: Utah Department of Natural Resources Technical Publication 73, 66 p.

Mower, R.W., and Cordova, R.M., 1974, Water resources of the Milford area, Utah, with emphasis on ground water: Utah Department of Natural Resources Technical Publication 43, 106 p.

Mower, R.W., and Feltis, R.D., 1968, Ground-water hydrology of the Sevier Desert, Utah: U.S. Geological Survey Water-Supply Paper 1854, 75 p.

National Research Council, 1985, Liquefaction of soils during earthquakes: National Academy Press, Washington, D.C., 240 p.

Powell, Keith, 1974, Blue Cut to East Price soil stability study: Utah Department of Highways unpublished report, 2 p.

Price, Don, in press, Ground-water resources of the central Wasatch Front area, Utah: Utah Geological and Mineral Survey Map 54-C, scale 1:100,000.

Price, Don, and Arnow, Ted, 1974, Summary appraisal of the nation's ground-water resources - Upper Colorado Region: U.S. Geological Survey Professional Paper 813-C, 40 p.

Price, Don, and Bolke, E.L., 1970, Hydrologic reconnaissance of the Sink Valley area, Tooele and Box Elder Counties, Utah: Utah Department of Natural Resources Technical Publication 26, 34 p.

Price, Don, and Conros, L.S., 1988, Ground-water resources of the southern Wasatch Front area, Utah: Utah Geological and Mineral Survey Map 55-C, scale 1:100,000, in press.

Price, Don, and Waddell, K.M., 1973, Selected hydrologic data in the Upper Colorado River basin: U.S. Geological Survey Hydrologic Investigations Atlas HA-477, scale 1:2,500,000.

Razem, A.C., and Steiger, J.I., 1981, Ground-water conditions in Tooele Valley, Utah, 1976-78: Utah Department of Natural Resources Technical Publication 69, 95 p.

Robinson, G.B., Jr., 1971, Ground-water hydrology of the San Pitch River drainage basin, Sanpete County, Utah: U.S. Geological Survey Water-Supply Paper 1896, 80 p.

Sandberg, G.W., 1966, Ground-water resources of selected basins in southwestern Utah: Utah State Engineer Technical Publication 13, 46 p.

Saxon, F.C., 1972, Water-resource evaluation of Morgan Valley, Morgan County, Utah: Master's thesis, University of Utah, 116 p.

Seiler, R.L., and Waddell, K.M., 1984, Reconnaissance of the shallow-unconfined aquifer in Salt Lake Valley, Utah: U.S. Geological Survey Water-Resources Investigations Report 83-4272, 34 p.

Stephens, J.C., 1974a, Hydrologic reconnaissance of the northern Great Salt Lake Desert and summary hydrologic reconnaissance of northwestern Utah: Utah Department of Natural Resources Technical Publication 42, 55 p.

———1974b, Hydrologic reconnaissance of the Wah Wah Valley drainage basin, Millard and Beaver Counties, Utah: Utah Department of Natural Resources Technical Publication 47, 53 p.

———1976, Hydrologic reconnaissance of the Pine Valley drainage basin, Millard, Beaver, and Iron Counties, Utah: Utah Department of Natural Resources Technical Publication 51, 38 p.

———1977, Hydrologic reconnaissance of the Tule Valley drainage basin, Juab and Millard Counties, Utah: Utah Department of Natural Resources Technical Publication 56, 37 p.

Stephens, J.C., andHood, J.W., 1973, Hydrologic reconnaissance of Pilot Valley, Utah and Nevada: Utah Department of Natural Resources Technical Publication 41, 38 p.

Stephens, J.C., and Sumsion, C.T., 1978, Hydrologic reconnaissance of the Dugway Valley - Government Creek area, west-central Utah: Utah Department of Natural Resources Technical Publication 59, 42 p.

Sumsion, C.T., 1971, Geology and water resources of the Spanish Valley area, Grand and San Juan Counties, Utah: Utah Department of Natural Resources Technical Publication 32, 45 p.

Trickler, D.L., and Hall, D.L., 1984, Soil survey of Fairfield-Nephi area, Utah, parts of Juab, Sanpete, and Utah Counties: U.S. Soil Conservation Service and Forest Service in cooperation with U.S. Bureau of Land Management and Utah Agricultural Experiment Station, 361 p.

Utah Division of Water Resources, (1964-present), Developing a state water plan - ground-water conditions in Utah, spring of 19--: Utah Division of Water Resources Cooperative Investigations Reports, published annually.

Van Horn, Richard, 1975, Largest known landslide of its type in the United States: a failure by lateral spreading in Davis County, Utah: Utah Geology, v. 2, no. 1, p. 82-87.

Waddell, K.M., Seiler, R.L., Santini, Melissa, and Solomon, D.K., 1987, Ground-water conditions in Salt Lake Valley, Utah, 1969-83, and predicted effects of increased withdrawals from wells: Utah Department of Natural Resources Technical Publication 87, 69 p.

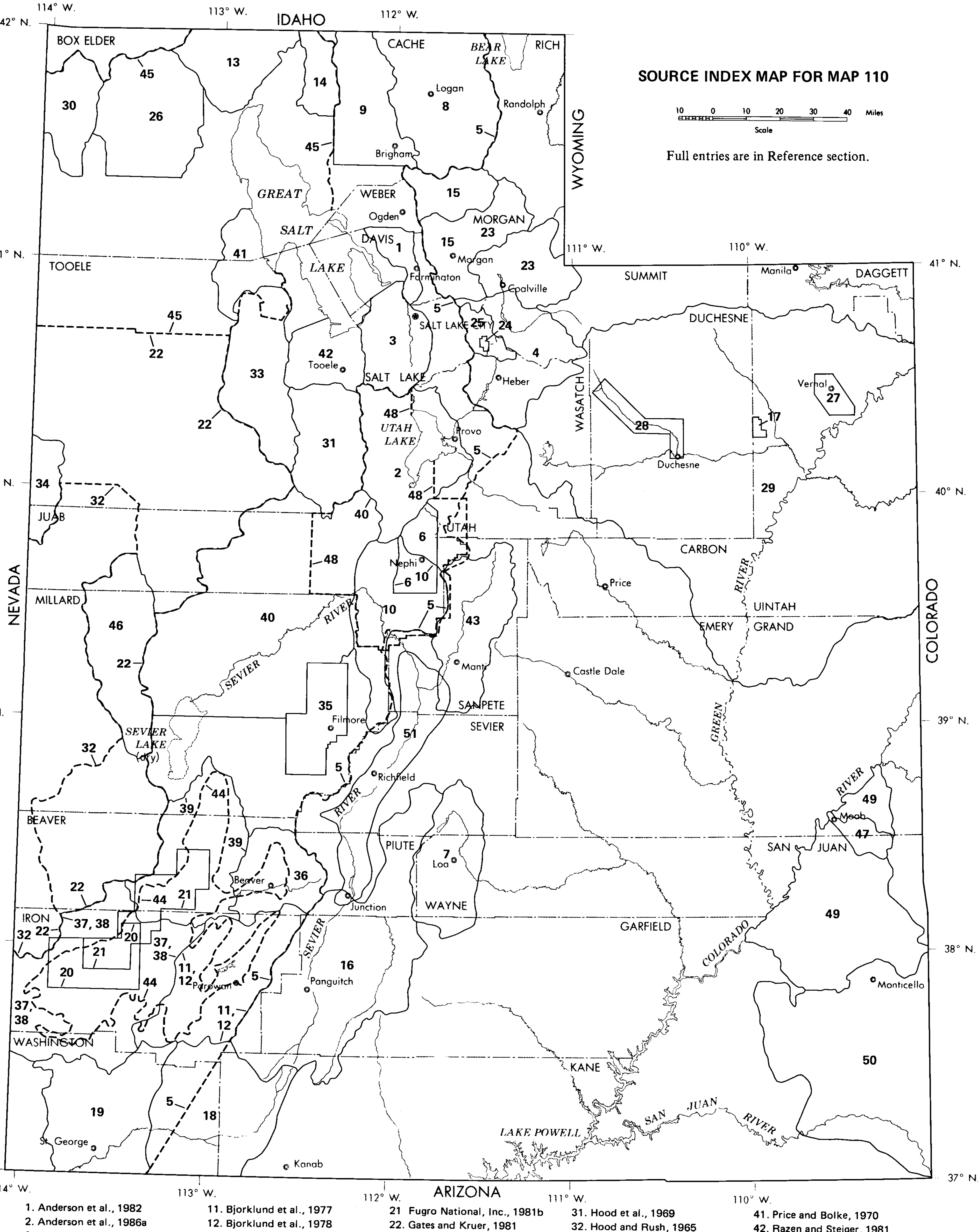
Weir, J.E., Jr., Maxfield, E.B., and Hart, I.M., 1983, Reconnaissance of the geohydrology of the Moab-Monticello area, western Paradox Basin, Grand and San Juan Counties, Utah: U.S. Geological Survey Water-Resources Investigations 83-4098, 59 p.

White, W.N., 1932, A method of estimating ground-water supplies based on discharge by plants and evaporation from soil - results of investigations in Escalante Valley, Utah, *in* Contributions to the Hydrology of the United States, 1932: U.S. Geological Survey Water-Supply Paper 659, p. 1-105.

Whitfield, M.S., Jr., Thordarson, William, Oatfield, W.J., Zimmerman, E.A., and Rueger, B.F., 1983, Regional hydrology of the Blanding-Durango area, southern Paradox Basin, Utah and Colorado: U.S. Geological Survey Water-Resources Investigations Report 83-4218, 88 p.

Youd, T.L., 1977, Discussion of "Brief review of liquefaction during earthquakes in Japan", by Kuribayashi, Eiichi, and Tatsuoka, Fumio, 1975: Soils and Foundations, v. 17, no. 1, p. 82-85.

Young, R.A., and Carpenter, C.H., 1965, Ground-water conditions and storage in the central Sevier Valley, Utah: U.S. Geological Survey Water-Supply Paper 1787, 95 p.



1. Anderson et al., 1982
2. Anderson et al., 1986a
3. Anderson et al., 1986b
4. Baker, C.H. Jr., 1970
5. Bedinger et al., 1984b
6 Bjorklund, L.J., 1967
7. Bjorklund, L.J., 1969
8. Bjorklund and McGreevy, 1971
9. Bjorklund and McGreevy, 1974
10. Bjorklund and Robinson, 1968
11. Bjorklund et al., 1977
12. Bjorklund et al., 1978
13. Bolke and Price, 1969
14. Bolke and Price, 1972
15. Carley et al., 1980
16. Carpenter et al., 1967
17. Christenson, G.E., 1981
18. Cordova, R.M., 1981
19. Cordova et al., 1972
20. Fugro National, Inc., 1981a
21 Fugro National, Inc., 1981b
22. Gates and Kruer, 1981
23. Gates et al., 1984
24. Gill and Lund, 1984
25. Holmes et al., 1986
26. Hood, J.W., 1971
27. Hood, J W., 1977a
28. Hood, J.W., 1977b
29. Hood et al., 1976
30. Hood and Price, 1970
31. Hood et al., 1969
32. Hood and Rush, 1965
33. Hood and Waddell, 1968
34. Hood and Waddell, 1969
35. Mower, R.W., 1965
36. Mower, R.W., 1978
37. Mower, R.W., 1981
38. Mower, R.W., 1982
39. Mower and Cordova, 1974
40. Mower and Feltis, 1968
41. Price and Bolke, 1970
42. Razen and Steiger, 1981
43. Robinson, G.B. Jr., 1971
44. Sandberg, G.W., 1966
45. Stevens, J.C., 1974a
46. Stevens, J.C., 1977
47. Sumsion, C.T., 1971
48. Trickler and Hall, 1984
49. Weir et al., 1983
50. Whitfield et al., 1983
51. Young and Carpenter, 1965